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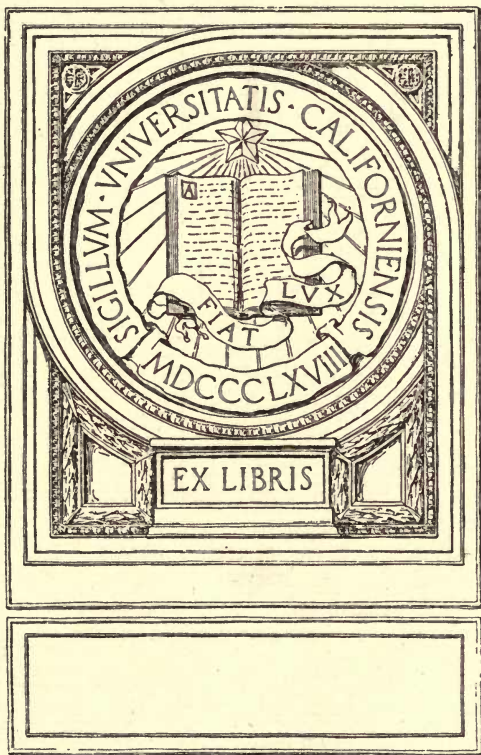
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UNIVERSITY OF CALIFORNIA
DEPARTMENT OF CIVIL ENGINEERING
TESTING LABORATORY

CHARLES DERLETH, JR.

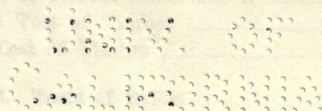
Director

LABORATORY INSTRUCTIONS FOR
TESTS OF METAL, TIMBER,
BRICK, CONCRETE

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PREFACE

This manual has been prepared for Civil Engineering students who take the course in testing of structural materials at the University of California. Its purpose is to expedite laboratory work by relieving the instructor from the detailed direction of students.

A treatment of the underlying theoretical principles is not included. For this the student is referred to earlier allied courses and standard treatises.

The main objects of the course are to acquaint the student with the methods of testing structural materials, to afford practice in the writing of reports, and to illustrate the fundamental laws of strength of materials.



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GENERAL RULES FOR LABORATORY WORK

Prompt and regular attendance is required of every student.

Tests are performed by parties of three students each, consisting of an operator, who manipulates apparatus; an observer who announces readings; and a recorder, who keeps the log sheets of the test. Students are to change positions in regular order.

In making tests, students working together share alike. Computations are to be checked but reports are to be written independently.

The assignments of tests, materials, and testing machines are posted on the laboratory bulletin board. Directions for assigned tests are to be carefully read before coming to the laboratory.

Upon completion of tests all apparatus used is to be thoroughly cleaned. All waste is to be removed from tables, floor and testing machines. All polished surfaces of metal are to be dried and oiled.

Breakage of apparatus is to be reported immediately. Breakages due to carelessness will be charged to the student responsible for the damage.

OPERATION OF TESTING MACHINES

Study the operation of testing machines at every opportunity and become thoroughly familiar with their principle and mechanism. The machines in the laboratory are in operation daily; students are welcome to witness tests at any time.

Do not operate a machine for the first time without the assistance of the instructor.

Do not start a machine without determining the direction and speed with which it will move.

Do not start a machine too suddenly as there is danger of stripping a gear or throwing a belt.

Do not change the direction or speed without first stopping the machine.

Always center the specimen accurately in the machine.

In compression tests always use a spherical seated base-plate and adjust the upper bearing surface of the specimen parallel to the upper plate of the machine.

In tension tests observe closely the posted directions for use of wedge grips.

Before applying the load in any test, balance the weighing apparatus with the counterpoise at zero and the test specimen in the machine. Adjust the recoil nuts to be just loose. Keep poise arm continually balanced as load is being applied.

The speed of applying the load in any test must be such that the poise arm may be kept balanced easily. Always record the speed. The fastest speed should be used only for shifting the movable head to facilitate placing or removing specimens.

Observations on a test specimen for a certain indicated load should be taken only when the poise arm is balanced at that load. Do not move the counterpoise beyond the point at which

the failure occurs before taking the reading. As soon as the failure occurs, throw the machine out of gear; then record the indicated load.

Before leaving a machine, or when a test is finished, be sure that the clutches are properly thrown out and that the machine has stopped running.

CAUTION.—At times machines have been left running by operators with the result that parts have been broken.

References. Testing Machines and Methods:

1. The Materials of Construction. Johnson.
2. Handbook of Testing Materials. Martens.
3. Riehle & Co. Catalogues of Testing Machines.
4. Olsen & Co. Catalogues of Testing Machines.
5. Yearbook. American Society for Testing Materials.
6. Proceedings. American Society for Testing Materials.

WRITING OF REPORTS

Follow strictly the "General Rules for Notes, Problems, Reports and Theses," adopted by the Department of Civil Engineering.

Clearness, order of presentation, legibility and neatness will receive due consideration in grading the report. Lack of neatness is sufficient cause for rejection.

Observe the following order in arranging the report of each test

Title. This should indicate at a glance the scope of the test.

Purpose. Give briefly the object and significance of the test.

Material. Describe the materials tested. Give scale sketches of specimens; indicate dimensions; submit photographs of the failures.

Apparatus. Name all apparatus. Describe all special apparatus and testing machines used for the first time. Submit photograph of machine with specimen in place.

Method of Test. Describe all operations which have any bearing on the performance or success of the test.

Data. Submit a log sheet of the test. Describe the behavior of the material when tested.

Computations. State all formulas used; define all quantities; indicate numerical work. Ordinarily computations may be made with the slide rule. Submit final results on report form provided for the test. Arrange title on stress-strain diagrams with sufficient subheadings to fully explain the results obtained.

Submit each report in a standard folder within one week after the date of performance of tests. Reports returned for correction are due within one week after date of return.

NOTE:—In addition to the prescribed tests students will be held responsible for reference readings assigned at intervals during the course. These assignments are to be written in the manual under the heading "References," of the proper test.

PART I. TESTS OF METAL

TEST No. 1

COMMERCIAL TENSION TEST OF METAL

Purpose. To determine the strength and ductility of various metals when subjected to tension.

Material. One specimen each of steel, wrought iron, Norway iron, brass and cast iron.

Apparatus. Testing machine arranged for tension test. Micrometer caliper, steel scale graduated to one-tenth of an inch, pair 6-inch dividers, center punch, small hammer, V-plate, chalk.

Operations. Obtain with the micrometer caliper the average dimensions of the net section of each specimen. With center punch, lightly mark the ends of a 2-inch gauge length and divide this length into $\frac{1}{2}$ -inch spaces. Chalk the surface at one end of the gauge length.

Insert a specimen in the machine. Read the directions for operation of testing machines on page 5.

Determine the yield point by observing when the poise arm momentarily drops. Check this load by noting with the dividers when the distance between end punch marks begins to increase rapidly. Note the maximum load and the load at final rupture. Remove the specimen from the machine. Measure the elongation between end and adjacent intermediate punch marks. With the caliper measure the dimensions of the reduced section. Observe and record the character of fracture. Test each specimen in a similar manner.

Report. Submit data on Form 1 and summary of results on a second sheet of Form 1.

COLD BENDING TEST OF METAL

Purpose. To study the ductility of metal when subjected to cold bending.

Material. One bar each of medium steel, soft steel, hard steel, grade A wrought iron.

Apparatus. Cold bending machine, steel scale.

Operations. Measure the dimensions of the specimens. Bend the wrought iron and soft steel 180 degrees flat upon itself; the medium steel, 180 degrees about a diameter equal to the thickness of the material; the hard steel, 180 degrees about a diameter equal to three times the thickness of the bar. To bend a specimen flat upon itself, first bend it 180 degrees about a diameter equal to its thickness, then complete the bend by applying a steady pressure in a testing machine arranged for compression. For each specimen note the angle when cracks or other signs of failure appear. Examine the bent portion carefully.

Report. Describe the behavior of each specimen under test.

References:

TEST No. 3

ELASTIC TENSION TEST OF METAL

Purpose. To determine the coefficient of elasticity and elastic limit of metal when subjected to tension.

Material. One specimen each of medium steel, wrought iron and Norway iron.

Apparatus. Testing machine arranged for tension test. Micrometer caliper, steel scale graduated to one-tenth of an inch, pair large dividers, V-plate, center punch, small hammer, Riehle-Yale extensometer with battery and bell.

Operations. With the micrometer caliper measure the diameter of each specimen at several points throughout the turned section. Record the mean value. Mark lightly with center punch a gauge length of 8 inches with intermediate points 1 inch apart. Attach extensometer firmly with gauge bar set at 8 inches.

Read the directions for operation of testing machines on page 5.

Adjust specimen securely in the machine. Remove gauge bar from extensometer. Read micrometers for an initial load of 1000 lb. and for each 1000 lb. load increment thereafter. Remove extensometer just after reaching the elastic limit.

Continue application of load until failure occurs. Obtain load for each elongation increment of one-tenth of an inch as determined with dividers. Note maximum load and load at final rupture. Determine the percentages of elongation and contraction as in Test No. 1. Observe and record the character of fracture.

Report. Submit data on Form 6A and summary of results on Form 6. For each specimen construct two stress-strain diagrams on the same sheet of coördinate paper, using loads as ordinates

and elongations as abscissas. For diagram No. 1 use loads up to the elastic limit only. Draw an averaging straight line through the plotted points. Employ scales such that this line will make an angle with the X axis of about 60 degrees. Through the origin draw a second straight line parallel to this line. Mark on it the elastic limit. This second line represents the true relation between stress and strain in the specimen up to the elastic limit. For diagram No. 2 use loads from elastic limit to rupture with the origin the same as for diagram No. 1.

References:

1. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

2. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

3. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

4. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

5. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

6. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

7. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

8. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

9. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

10. "The Elastic Limit of Metals," by J. E. Gordon, *Philosophical Magazine*, 1914, Vol. 17, No. 10, p. 105.

COMMERCIAL TENSION TEST OF WIRE

Purpose. To determine the strength and ductility of wire.

Material. One specimen each of soft steel, hard drawn steel, hard drawn brass, hard drawn copper, wire cable strands.

Apparatus. Wire testing machine, micrometer caliper, steel scale graduated to one-tenth of an inch, pair large dividers, center punch, small hammer, chalk.

Operations. Unravell the wire strands; note relative positions of various sizes of wire. Obtain the average diameter of each wire with the caliper. Test each wire separately, noting only the maximum load.

Measure the diameter of each of the other wire specimens at three points throughout its length. With center punch mark lightly an 8 inch gauge length on each wire.

Read the directions for operation of testing machines on page 5.

Determine as in Test No. 1 the yield point, maximum load, load of final rupture, percentages of elongation and contraction, and character of fracture.

Report. Submit data on Form 1 and summary of results on a separate sheet of Form 1. Calculate the theoretical strength of the wire cable.

References:

TEST No. 5

TENSION TEST OF WIRE CABLE

Purpose. To determine the strength of wire cable.

Material. Wire cable specimens with ends encased in babbitt metal.

Apparatus. Testing machine arranged for tension test, scale, caliper.

Operations. Measure the diameter of each cable. Count the number of strands. Note the number of wires per strand, also their diameters.

Read the directions for operation of testing machines on page 5.

Obtain the ultimate resistance of each cable. Note the load at which the first wire ruptures. Observe the manner of failure of the cable.

Report. Using the data of Test No. 4 calculate the efficiency of the cables. Draw enlarged cross-sectional sketches of each specimen.

References:

ELASTIC TENSION TEST OF WIRE

Purpose. To determine the coefficient of elasticity and elastic limit of wire.

Material. One specimen each of soft steel, hard drawn steel, hard drawn brass, hard drawn copper.

Apparatus. Wire testing machine, micrometer caliper, steel scale graduated to one-tenth of an inch, pair large dividers, wire extensometer with battery and bell.

Operations. With the caliper measure the diameter of each wire at three points throughout its length. Attach the extensometer with its micrometers set at zero; its gauge length is then 10 inches.

Read the directions for operation of testing machines on page 5.

Read micrometers for an initial load of 50 lb. Apply the load in regular increments such that eight readings may be obtained below the elastic limit. Measure elongations with the extensometer up to 0.5 inch. Obtain the maximum load, percentages of elongation and contraction, and character of fracture.

Report. Submit data on Form 6A and summary of results on Form 6. Construct a stress-strain diagram for each specimen as outlined in Test No. 3.

References:

ELASTIC COMPRESSION TEST OF METAL

Purpose. To determine the coefficient of elasticity and elastic limit of metal when subjected to compression.

Material. One specimen each of steel, wrought iron, Norway iron, brass and cast iron.

Apparatus. Testing machine arranged for compression test, spherical seated base-plate, hardened steel plates, compressometer with battery and bell, compressometer collars, micrometer caliper.

Operations. With the micrometer caliper measure the average diameter of each specimen. Attach compressometer collars to specimens, using a 2-inch gauge length. Place the specimen in the machine between the hardened steel plates.

Read the directions for operation of testing machines on page 5.

Read compressometer for an initial load of 1000 lb. and for each 3000-lb. load increment thereafter. When near the elastic limit take several readings with load increments of 1000 lb. Continue until the applied load exceeds the elastic limit by 20,000 lb.

Report. Submit data on Form 7A and summary of results on Form 7. Construct a stress-strain diagram for each specimen as outlined in Test No. 3.

References:

TORSION TEST OF METAL

Purpose. To determine the strength of various metals when subjected to torsion.

Material. One specimen each of steel, wrought iron, Norway iron, brass, cast iron.

Apparatus. Thurston's torsion machine, platform scale, pendulum support, hammer, punch, wedges, micrometer caliper, autographic diagram paper, calibrating bar, long scale.

Operations. Calibration of Machine. Place paper tightly over recording drum. With pendulum vertical release pencil and by revolving drum draw a zero line. Determine weight of pendulum when in a horizontal position as indicated by 90° mark on the wooden scale. Measure lever arm and calculate maximum moment. With pendulum horizontal draw a line corresponding to the maximum moment. The maximum moment divided by the distance between zero and maximum moment lines gives the ordinate scale in inch pounds per inch. Determine the scale of abscissas in radians per inch.

Insert the calibrating bar tightly with the wedges. Raise the pendulum with the worm gearing; the pencil will mark the position of approximately the zero ordinate. Remove paper from drum and mark it calibration sheet.

Testing of Specimens. With the micrometer caliper measure the average diameter of the turned portion of each specimen. For each specimen use a new sheet of paper; mark on each sheet the line of zero moment. Tabulate the data on the sheet.

Wedge the specimen tightly in place. With pendulum vertical readjust the pencil point accurately to the line of zero moment. Apply the load to the specimen by means of the worm gear, turning the crank with a slow uniform motion. Continue

application of the load until the specimen fails. Note the character of the fracture.

Report. Submit autographic diagrams and calibration sheet. Report summary of results on Form 3.

References:

ELASTIC TORSION TEST OF METAL

Purpose. To determine the elastic properties of various metals when subjected to torsion.

Material. One specimen each of steel, Norway iron and wrought iron.

Apparatus. Riehlé torsion machine, tortometer, micrometer caliper, scale.

Operations. Measure the average diameter of the turned portion of each specimen with the micrometer caliper. Set the space bars on the tortometer for a 2-inch gauge length. Adjust the tortometer on the specimen, taking care to have its axis coincident with that of the test piece. Place the specimen in the machine so that the tortometer dial arm is adjacent to the stationary head and is approximately horizontal. Move the straining head into position and wedge the specimen tightly. Set the dial pointers at zero for an initial moment of 25 foot pounds. Take readings to hundredths of a degree on both dials for moment increments of 25 foot pounds. In the vicinity of the elastic limit use increments of 10 foot pounds. After passing the elastic limit proceed with the test at a uniform speed. Keep the poise arm balanced; note the moment for each 30 degree increment in angle of twist. Record the maximum moment, also angle of torsion at final rupture. Note the character of fracture.

Report. Submit data on Form 3A and summary of results on Form 3. For each specimen plot a curve, using moments as ordinates and angles of torsion as abscissas. Follow the method outlined in Test No. 3.

SHEARING TEST OF METAL

Purpose. To determine the shearing strength of various metals.

Material. Turned lengths of steel, Norway iron, wrought iron and brass.

Apparatus. Testing machine arranged for compression test, metal shearing tool, micrometer caliper.

Operations. With the micrometer caliper measure the diameter of each specimen. Insert the specimen into the shearing tool so as to subject it to single shear.

Read the directions for operation of testing machines on page 5.

Obtain the maximum load and load at final rupture. Note the character of fracture.

Report. Submit data and summary of results on separate sheets of Form 4.

References:

TESTS OF RIVETED JOINTS

Purpose. To determine the strength of riveted joints.

Material. Single lap joint with two $\frac{5}{8}$ -inch rivets, single lap joint with two $\frac{1}{2}$ -inch rivets.

Apparatus. Testing machine arranged for tension test, scale, caliper.

Operations. Measure the important dimensions of the specimens.

Read the directions for operation of testing machines on page 5.

Insert filler plates on opposite sides in the upper and lower head of the machine so that when the load is applied there is no tendency to bend the plates of the joint. Determine the maximum load. Describe the behavior of the specimen during the test. In what manner did it fail?

Report. Submit data and summary of results on separate sheets of Form 4.

References:

IMPACT FLEXURE TEST OF METAL

Purpose. To determine the strength, elastic properties and manner of failure of iron and steel in bending when subjected to suddenly applied loads.

Material. One beam each of steel and wrought iron about 4 feet long.

Apparatus. Turner impact testing machine arranged for flexure test, wrench, caliper, scale, autographic diagram paper.

Operations. Measure the dimensions of the specimens. Using a span length of 36 inches, clamp the specimens securely in place and symmetrically under the hammer. Attach the paper to the recording drum and see that the stylus of the tuning fork is properly adjusted.

Read the directions for operation of testing machines on page 5.

Lower the hammer so that it just touches the surface of the specimen; revolve the drum and mark the datum line upon the record. Record the static deflection with the hammer resting on the beam. Note the weight of hammer. Drop the hammer from heights successively increased by a constant quantity until the specimen fails. Record initial height, increment of height and number of drops. When hammer is about to drop, strike tuning fork to cause it to vibrate and as hammer falls rotate the drum slowly, continuing until vibration of the specimen ceases. For each drop measure the deflection, the rebound and the permanent set. Note the nature of the failure. Use a new sheet for each test.

Report. Submit data and summary of results in tabular form. Include a typical record sheet. Compute the fiber stresses at the elastic limit and maximum load, the modulus of elasticity

and the modulus of resilience. For each specimen plot a curve, using heights of drop as ordinates and squares of deflections as abscissas. The point at which the curve departs from a straight line indicates the elastic limit.

References:

TRANSVERSE TEST OF CAST IRON

Purpose. To determine the flexural strength and coefficient of elasticity of cast iron.

Materials. Two specimens $1 \times 2 \times 26$ inches and two specimens $1\frac{1}{4}$ inches in diameter by 14 inches long.

Apparatus. Testing machine arranged for cross-bending test, scale, caliper, deflectometer.

Operations. Measure the dimensions of each specimen.

Read the directions for operation of testing machines on page 5.

Test the long specimens flatwise with center loading on a 24-inch span. Read deflection for each load increment of 100 lb. Obtain maximum load and deflection for all specimens. Test cylindrical specimens with center loading on a 12-inch span. Read deflections for each load increment of 200 lb.

Report. Submit data and summary of results in tabular form. For each specimen plot a curve, using center loads as ordinates and deflections as abscissas. Compute the modulus of rupture and coefficient of elasticity for each specimen.

References:

CALIBRATION OF A TESTING MACHINE

Purpose. To compare the force actually exerted by a testing machine with the load indicated on the dial.

Apparatus. Calibrating bar of known coefficient of elasticity, testing machine to be calibrated, arranged for tension test, spherical seated screw grips to fit calibrating bar, calibration extensometer with battery and bell.

Operations. Attach extensometer tightly and concentrically to the calibrating bar, using the longest gauge length possible, Note the gauge length, the diameter of the bar and its coefficient of elasticity.

Read the directions for operation of testing machines on page 5.

Read the micrometers for an initial load of 2000 lb. Take special care to keep the poise arm balanced while micrometers are being read. Take micrometer readings for increments of load equal to about one-tenth of the maximum load to be applied. Do not exceed the safe load for the bar which is stamped on its end; this load is slightly less than its elastic limit. Take a second set of readings for the applied load, decreasing from the maximum to the initial load.

Report. Submit a tabular summary of indicated loads and corresponding micrometer readings. From the known coefficient of elasticity of the calibrating bar and the observed strains compute the corresponding true loads. Draw a stress-strain diagram using indicated loads as abscissas and observed strains as abscissas. On the same sheet draw the true stress-strain diagram for the calibrating bar. What percentage of error do the indicated readings show?

References:

References

PART 2. TESTS OF TIMBER

TEST No. 15

FLEXURE TEST OF TIMBER

Purpose. To determine the strength and coefficient of elasticity of timber when subjected to bending.

Material. Two pieces each of Douglass fir and redwood.

Apparatus. Testing machine arranged for flexure test, third point loading beam, deflection scale, steel square, two steel gages, two wooden bolsters, hammer and small finishing nails, weighing scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentage of sapwood in Douglas fir and heartwood in redwood. Make sketches showing end and side views, note any defects. Test one beam of each species with center loading and the other with third point loading. Mark the center of all beams with a pencil the center of the span, also the points of load application and support. Fast the deflection scale on small nails driven at the central surface over the supports. Place the beam upon the supports, using the steel plates to prevent the knife edges from crushing the wood. Apply the load through the wooden bolts. Adjust the deflectionometer to read zero for zero load.

Read the deflection for operation of testing machine as page 5.

Apply the load in increments of about one-tenth of the estimated ultimate load. Read the center deflection at each increment of load, and compute the maximum. Obtain the maximum load and corresponding deflection. Note the nature of the failure.

References:

PART 2. TESTS OF TIMBER

TEST No. 15

FLEXURE TEST OF TIMBER

Purpose. To determine the strength and coefficient of elasticity of timber when subjected to bending.

Material. Two pieces each of Douglas fir and redwood.

Apparatus. Testing machine arranged for flexure test, third-point loading beam, deflectometer, scale, steel square, two steel plates, two wooden bolsters, hammer and small finishing nails, weighing scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of sapwood and heartwood, also the percentages of springwood and summerwood. Make sketches showing end and side views; note any defects. Test one beam of each species with center loading and the other with third-point loading. Mark on the sides of all beams with pencil the center of the span, also the points of load application and support. Rest the deflectometer on small nails driven at the neutral surface over the supports. Place the beam upon the supports, using the steel plates to prevent the knife edges from crushing the wood. Apply the load through the wooden bolsters. Adjust the deflectometer to read zero for zero load.

Read the directions for operation of testing machines on page 5.

Apply the load in increments of about one-tenth of the estimated ultimate load. Read the center deflection at each increments of load without stopping the machine. Obtain the maximum load and corresponding deflection. Note the nature of the failure.

After the test determine the percentage of moisture in each specimen as follows: Cut a half-inch disc transversely from the beam at the quarter point. Weigh the disc to one-tenth of a gram. Place it in the drying oven at 200° F. and allow it to dry until the variation between two successive weights over an interval of twenty-four hours is less than 0.5 per cent. The loss in weight expressed in percent of the dry weight will give approximately the moisture content of the piece from which the disc was cut.

Report. Submit data on Form 5A and summary of results on Form 5. Plot a curve for each specimen, using loads in pounds as ordinates and center deflections in inches as abscissas. Choose scales such that the slope of the diagram near the origin will be about 60° . Mark the elastic limit.

References:

ELASTIC COMPRESSION TEST OF TIMBER

Purpose. To determine the strength and coefficient of elasticity of wood when subjected to compression parallel to grain.

Material. One specimen each of Douglas fir, redwood and white oak.

Apparatus. Testing machine arranged for compression, spherical seated base-plate, compressometer with battery and bell, compressometer collars with space bars, scale, Harvard trip balance and set of weights.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of heartwood and sapwood, also the percentages of springwood and summerwood. Make sketches showing end and side views; note any defects. Attach the compressometer collars using the longest gauge length possible. Note the gauge length.

Read the directions for operation of testing machines on page 5.

Make a zero reading of the compressometer for an initial load of 1000 lb. Apply the load in increments of about one-tenth of the estimated ultimate resistance of the specimen. Stop the machine after each increment to obtain the compressometer reading. Obtain the maximum load and corresponding strain. Note the kind of failure. Determine the percentage of moisture in each specimen as outlined in Test No. 15.

Report. Submit data on Form 2A and summary of results on Form 2. For each specimen construct a stress-strain diagram, using loads in pounds as ordinates and compressions in inches as abscissas. Choose scales such that the slope of the diagram near the origin will be about 60° . Mark the elastic limit.

References:

CLASSIC COMPRESSION TEST OF TIMBER

1. To determine the strength and modulus of elasticity of a specimen, a specimen of known length and cross-section is subjected to compression parallel to grain.

2. The specimen is supported at both ends by rigid supports, and the load is applied by a rigid platen, the specimen being held between two platens.

3. The specimen is supported at both ends by rigid supports, and the load is applied by a rigid platen, the specimen being held between two platens.

4. The specimen is supported at both ends by rigid supports, and the load is applied by a rigid platen, the specimen being held between two platens.

5. The specimen is supported at both ends by rigid supports, and the load is applied by a rigid platen, the specimen being held between two platens.

6. The specimen is supported at both ends by rigid supports, and the load is applied by a rigid platen, the specimen being held between two platens.

ELASTIC FLEXURE TEST OF TIMBER

Purpose. To determine the strength and elastic properties of timber when subjected to bending by experimentally locating the position of the neutral surface.

Material. One piece of Douglas fir $4 \times 6 \times 72$ inches.

Apparatus. Testing machine arranged for flexure test, third-point loading beam, two grooved bearing plates at supports, four grooved bearing plates for applying load, two rollers, four wooden bolsters, flexure strainometer with battery and bell, scale, steel square, nails, thread, elastic band, deflection scale, platform scale.

Operations. Measure and weigh the specimen. Count the number of annual rings per radial inch. Determine the percentages of sapwood and heartwood, also the percentages of springwood and summerwood. Make sketches showing the end and side views; note any defects. The load is to be applied at the third points. Mark with pencil on the sides of the beam the center of the span, the points of load application and support, also the positions of micrometer collars, 5 inches on each side of the center. Attach micrometer collars so that both are in the same known position with respect to the beam cross section. Place beam in machine, attach battery and bell to strainometer. Drive a small nail at the neutral surface over each support. Attach deflection scale vertically at center of beam. Stretch thread in front of deflection scale from nail to nail, holding it taut by an elastic band at one end.

Read the directions for operation of testing machines on page 5.

Take zero readings of deflection scale and strainometer micrometers for an initial load of 100 lb. Take readings for load increments of 250 lbs. Remove strainometer after reach-

ing elastic limit. Determine the maximum load and corresponding deflection. Note the nature of the failure. Determine the percentage of moisture as outlined in Test No. 15.

Report. Submit data on Form 8A and summary of results on Form 8. Plot a curve, using loads as ordinates and deflection as abscissas. On the same sheet but with origins shifted along the X axis, plot curves using loads, to the same scale as above, as ordinates and fibre strains as abscissae. Mark the elastic limit on these curves.

References:

IMPACT FLEXURE TEST OF TIMBER

Purpose. To determine the strength, elastic properties and manner of failure of wood in bending when subjected to suddenly applied loads.

Material. Two pieces each of Douglas fir and redwood.

Apparatus. Turner impact testing machine arranged for flexure test, wrench, scale, square, autographic diagram paper, weighing scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of sapwood and heartwood, also the percentages of springwood and summerwood. Make sketches showing the end and side views; note any defects. Mark with pencil on the sides of each beam the center of the span and points of support. Clamp the specimen securely in place and symmetrically under the hammer. Attach the paper to the recording drum and see that the stylus of the tuning fork is properly adjusted.

Read the directions for operation of testing machines on page 5.

Lower the hammer so that it just touches the surface of the specimen; revolve the drum and mark the datum line upon the record. Record the static deflection with the hammer resting on the beam. Note the weight of hammer. Drop the hammer from heights successively increased by a constant quantity until the specimen fails. Record initial height, increment of height and number of drops. When hammer is about to drop, strike tuning fork to cause it to vibrate and as hammer falls, rotate the drum slowly, continuing until vibration of the specimen ceases. For each drop measure the deflection, the rebound and the permanent set. Note the nature of the failure. Use a new sheet for each test unless the sheet is less than half covered.

Determine the percentage of moisture in each specimen as outlined in Test No. 15.

Report. Submit data in tabular form and summary of results on Form 10. Include a typical autographic diagram. For each specimen plot a curve using heights of drop as ordinates and squares of deflections as abscissas. Mark the elastic limit.

References:

IMPACT COMPRESSION TEST OF TIMBER

Purpose. To determine the strength of timber in compression when subjected to suddenly applied loads.

Material. One specimen each of Douglas fir, redwood and white oak.

Apparatus. Turner impact machine arranged for compression test, wrench, scale, autographic diagram paper, scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of sapwood and heartwood, also the percentages of springwood and summerwood. Make sketches showing the end and side views; note any defects. Clamp the specimen securely in place and symmetrically under the hammer. Attach the paper to the recording drum and see that the stylus of the tuning fork is properly adjusted. Note the weight of the hammer.

Read the directions for operation of testing machines on page 5.

Carefully lower the hammer until it rests on the specimen. Revolve the drum and mark the datum line upon the record. Drop the hammer from heights successively increased by a constant quantity until the specimen fails.

Record initial height, increment of height and number of drops. When the hammer is about to drop, strike tuning fork to cause it to vibrate and as hammer falls, rotate the drum slowly, continuing until vibration of specimen ceases. For each drop measure the deflection, the rebound and the permanent set. Note the nature of the failure. Use a new sheet for each test unless the sheet is less than half covered. Determine the percentage of moisture in each specimen as outlined in Test No. 15.

Report. Submit data in tabular form and summary of results on form similar to Form 10. Include a typical autographic diagram. For each specimen plot a curve, using heights of drop or ordinates and squares of deflections as abscissas. Mark the elastic limit.

References:

COMMERCIAL COMPRESSION TEST OF TIMBER

Purpose. To determine the strength of timber when subjected to compression parallel and perpendicular to grain.

Material. Two specimens each of Douglas fir and redwood for compression parallel to grain and two specimens each of Douglas fir and redwood for compression perpendicular to grain.

Apparatus. Testing machine arranged for compression test, spherical seated base-plate, platform scale, measuring scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of heartwood and sapwood, also the percentages of springwood and summerwood. Make sketches showing the end and side views; note any defects.

Read the directions for operation of testing machines on page 5.

Determine the maximum load and nature of failure for each specimen. Determine percentage of moisture as outline in Test No. 15.

Report. Submit data and summary of results in tabular form.

References:

LONGITUDINAL SHEARING TEST OF TIMBER

Purpose. To determine the strength of timber when subjected to shear parallel to grain.

Material. Two specimens each of Douglas fir, redwood and white oak.

Apparatus. Testing machine arranged for compression test, wood shearing tool, measuring scale, wrench, weighing scale.

Operations. Measure and weigh each specimen. Count the number of annual rings per radial inch. Determine the percentages of sapwood and heartwood, also the percentages of springwood and summerwood. Make sketches showing the end and side views; note any defects. Place the specimen in the shearing tool, tightening the screws so that it is rigidly held.

Read the directions for operation of testing machines on page 5.

Determine the maximum load for each specimen. Note the position of the failure.

Report. Submit data and summary of results on separate sheets of Form 4.

References:

PART 3. TESTS OF BRICK

TEST No. 22

COMPRESSION TEST OF BRICK

Purpose. To determine the crushing strength of brick when subjected to compression edgewise and flatwise.

Material. Three building brick, three paving brick.

Apparatus. Testing machine arranged for compression, spherical seated base-plate, weighing scale, plaster Paris, capping-plates, measuring scale.

Operations. Note the brand of each brick. Measure and weigh each specimen. If the capacity of the testing machine will not permit of testing a whole brick, test half of the specimen. Coat the bearing surfaces with a layer of plaster Paris about one-quarter of an inch thick; cap this squarely with the cast-iron plates. If the bearing surfaces are smooth blotting paper may be substituted for the plaster Paris.

Read the directions for operation of testing machines on page 5.

Test the building brick flatwise and the paving brick edgewise. Obtain the crushing load.

Report. Submit data and summary of results on separate sheets of Form 11.

References:

TRANSVERSE TEST OF BRICK

Purpose. To determine the modulus of rupture of brick.

Material. Three building brick, three paving brick.

Apparatus. Testing machine arranged for cross-bending test, special supports for transverse testing, measuring scale, square, weighing scale.

Operations. Note the brand of each brick. Measure and weigh each specimen. Test the building brick flatwise and the paving brick edgewise. Mark with pencil on the sides of each brick the center of the span and points of support 7 inches apart.

Read the directions for operation of testing machines on page 5.

Obtain the maximum center load for each brick. Note the character of the fracture. Save the half bricks resulting from the test for making compression and absorption tests.

Report. Submit data and summary of results on separate sheets of Form 11A.

References:

ABSORPTION TEST OF BRICK

Purpose. To determine the percentage of water absorbed by brick.

Material. One-half of each brick tested transversely.

Apparatus. Drying oven, thermometer, Harvard trip balance, set of weights, blotting paper, water storage tank.

Operations. Mark and weigh each sample. Dry the samples in the oven at 200° F. until the difference between two successive weights taken twenty-four hours apart is less than 0.5 per cent. Note the weight of each brick when dry. Submerge the specimens completely in the water storage tank. Reweigh each sample after periods of one-half hour, two hours and twenty-four hours. Before each weighing remove the excess surface moisture with blotting paper.

Report. Submit data and summary of results on separate sheets of Form 11. Determine the percentage of absorption by weight in terms of the weight of the dry specimen.

References:

RATTLER TEST OF BRICK

Purpose. To determine the resistance of brick to impact and abrasion.

Material. Enough paving brick of one kind so that their total volume will be as nearly as possible equal to 8 per cent of the volume of the rattler.

Apparatus. Standard rattler recommended by the National Paving Brick Manufacturers' Association, standard charge of shot, platform scale, rule, wrench.

Operations. See that the specimens are clean and dry before testing. Measure and weigh each specimen. Place the brick with the charge of shot in the rattler and close the cylinder. Rotate the rattler through 1800 revolutions at a speed of not less than $29\frac{1}{2}$ nor more than $30\frac{1}{2}$ revolutions per minute. Note the exact speed. Reweigh the specimens. Compute the loss in terms of the initial weight of dry brick.

Note the condition of the staves of the cylinder, also the condition of the shot. Obtain the total weight of each kind of shot.

Report. Submit data in tabular form and summary or results on Form 11A.

References:

PART 4. TESTS OF CONCRETE

TEST No. 26

ELASTIC COMPRESSION TEST OF CONCRETE

Purpose. To determine the coefficient of elasticity and strength of concrete.

Material. One 8 × 16 inch concrete cylinder.

Apparatus. Testing machine arranged for compression, spherical seated base-plate, two capping plates, plaster Paris, compressometer with battery and bell, compressometer collars with space bars, weighing scale.

Operations. Note the kinds and proportions of constituent materials, also the age of the specimen. Weigh the specimen. Coat the ends with a layer of plaster Paris about one-quarter of an inch thick. Cap the plaster Paris with plates placed squarely on the specimen. Attach the compressometer collars, using the longest gauge length possible. Note the gauge length.

Read the directions for operation of testing machines on page 5.

Apply a load of 2000 lb.; allow the specimen to stand with this load applied while the plaster Paris is setting. Make a zero compressometer reading for an initial load of 2000 lb. Read compressometer at each load increment of 2000 lb. until the first crack appears on the surface of the specimen. Then remove the compressometer and obtain the maximum load. Note the method of failure.

Report. Submit data and summary of results in tabular form. Compute the coefficient of elasticity for unit stresses of 500 lb. per square inch, 1000 lb. per square inch, and 1500 lb. per square inch. Draw a stress-strain diagram, using loads as ordinates and compressions as abscissas.

References:

PART 4. TESTS OF CONCRETE

CHAPTER 10. TESTS OF CONCRETE

TEST No. 28

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ELASTIC COMPRESSION TEST OF CONCRETE

1. This test method covers the determination of the modulus of elasticity and the coefficient of elasticity of concrete.

2. The test method is applicable to concrete of any strength.

3. The test method is applicable to concrete of any shape.

4. The test method is applicable to concrete of any size.

5. The test method is applicable to concrete of any age.

6. The test method is applicable to concrete of any type.

7. The test method is applicable to concrete of any condition.

8. The test method is applicable to concrete of any location.

9. The test method is applicable to concrete of any environment.

10. The test method is applicable to concrete of any use.

11. The test method is applicable to concrete of any purpose.

12. The test method is applicable to concrete of any function.

13. The test method is applicable to concrete of any role.

14. The test method is applicable to concrete of any position.

15. The test method is applicable to concrete of any status.

16. The test method is applicable to concrete of any condition.

17. The test method is applicable to concrete of any location.

18. The test method is applicable to concrete of any environment.

19. The test method is applicable to concrete of any use.

20. The test method is applicable to concrete of any purpose.

21. The test method is applicable to concrete of any function.

22. The test method is applicable to concrete of any role.

23. The test method is applicable to concrete of any position.

24. The test method is applicable to concrete of any status.

25. The test method is applicable to concrete of any condition.

26. The test method is applicable to concrete of any location.

27. The test method is applicable to concrete of any environment.

28. The test method is applicable to concrete of any use.

29. The test method is applicable to concrete of any purpose.

30. The test method is applicable to concrete of any function.

31. The test method is applicable to concrete of any role.

32. The test method is applicable to concrete of any position.

33. The test method is applicable to concrete of any status.

34. The test method is applicable to concrete of any condition.

ELASTIC FLEXURE TEST OF REINFORCED CONCRETE BEAM

Purpose. To determine the strength and elastic properties of reinforced concrete when subjected to bending by experimentally locating the position of the neutral surface.

Material. One reinforced concrete beam $4 \times 6 \times 72$ inches.

Apparatus. Testing machine arranged for flexure test, third-point loading beam, two grooved bearing plates at supports, four grooved bearing plates for applying load, two rollers, four wooden bolsters, flexure strainometer with battery and bell, plaster Paris, scale, steel square, thread, elastic band, deflection scale, thread holders, platform scale.

Operations. Note the kinds and proportions of constituent materials, also the age of the specimen. Measure and weigh the beam. The load is to be applied at the third points; the deflection is to be measured at the center. Mark with pencil on the sides of the beam the center of the span, the points of load application and support, also the positions of micrometer collars, 5 inches on each side of the center. Attach micrometer collars so that both are in the same known position with respect to the beam cross-section; the lower screws are to be fastened directly on to the steel reinforcement rods. Place beam in the machine. Attach a thread holder at the neutral surface over each support. Cushion the grooved bearing plates at the third points with a thin layer of plaster Paris. Paste deflection scale with plaster Paris vertically at center of span. Stretch the thread between holders and directly in front of deflection scale, holding it taut by an elastic band at one end. Attach battery and bell to strainometer.

Read the directions for operation of testing machines on page 5.

Take zero readings of deflection scale and strainometer micrometers for an initial load of 100 lb. Take readings for load increments of 100 lb. up to 1000 lb.; for load increments of 250 lb. thereafter. Remove the strainometer when the first indication of failure, other than a tension crack at the bottom of the beam, appears. Determine the maximum load and corresponding deflection. Note the nature of the failure.

Report. Submit data on Form 9A and summary or results on Form 9. Plot a curve using loads as ordinates and deflections as abscissas. On the same sheet but with origins shifted along the X axis, plot curves using loads, to the same scale as above, as ordinates and fibre strains in steel and concrete as abscissas.

References:

UNIVERSITY OF CALIFORNIA
DEPARTMENT OF CIVIL ENGINEERING
TESTING LABORATORY

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DIRECTOR

LABORATORY INSTRUCTIONS FOR TESTS
OF MACADAM AND BITUMINOUS
ROAD MATERIALS

BY
ARTHUR C. ALVAREZ

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PART 5

TESTS OF ROAD MATERIALS

MACADAM ROCK

TEST No. 28

ABRASION TEST

Purpose. To determine the resistance of macadam rock to wear.

Material. Two samples of different kinds of stone each containing at least 30 lb. of $2\frac{1}{2}$ in. crushed rock of uniform size.

Apparatus. Deval abrasion machine, balance sensitive to one-tenth of a gram, with metric weights, brush, two pans, 0.16 cm. ($\frac{1}{16}$ in.) mesh sieve.

Operations. See that the rock is dry. Brush the separate particles free of any adhering foreign matter. If the rock is very dirty, scrub it in water; then dry it thoroughly. Weigh out to the nearest tenth of a gram a test sample of each kind of rock amounting to 5 kilograms within 10 grams. Each test sample should contain as nearly fifty pieces as possible.

Unseal two of the cylinders; brush out all dust from within. Put one of the weighed test samples into each cylinder and reseal. Start the machine and rotate the cylinders for 10,000 revolutions as indicated by the automatic counter. Note the rate of revolution; it should be between 30 and 33 per minute.

Remove the abraded charge from one of the cylinders into the pan. Brush out all the fine dust. Brush off individually all the particles larger than $\frac{1}{2}$ in. and set them aside for weighing. Screen all the remainder through the No. 16 sieve. Add the residue to the particles larger than $\frac{1}{2}$ in. and weigh. The portion which passes the No. 16 sieve is considered abraded material;

determine its amount by subtracting from the weight of the original charge, the weight of material of the abraded charge which will not pass the No. 16 sieve. Express the amount of abraded material in two ways: 1. As a percentage by weight of the original charge; 2. As the French coefficient of wear which equals $\frac{400}{W}$, where W is the weight of abraded material in grams per kilogram of original charge. In a similar manner determine the amount of wear for the abraded sample in the second cylinder.

Give the principal dimensions of the Deval machine. On a sheet of $8\frac{1}{2} \times 11$ in. decimal-inch coördinate paper plot a curve having as abscissas French coefficients of wear up to 20 and as ordinates corresponding percentages of wear. This curve is for future reference to assist in transferring from one system of results to the other. So far as indicated by its resistance to wear, what is the value of this rock as a material for macadam roads?

References.

1. Bulletin 44, Office of Public Roads, U. S. Department of Agriculture.
2. Columbia School of Mines Quarterly, Vol. 26, No. 2, pp. 83-110.
3. Proceedings, American Society for Testing Materials, Vol. 13, pp. 983-995.
4. Yearbook, 1914, American Society for Testing Materials, p. 338.

CEMENTATION TEST OF MACADAM ROCK

Purpose. To determine the binding power of macadam rock dust.

Material. A sample of crushed rock containing at least 500 gm. of $\frac{1}{2}$ -in. material.

Apparatus. Ball mill, briquette former, Page impact machine equipped with one-kilogram hammer, five sheets of metallic recording paper, box of pasters, hot-air bath, desiccator, brush, spatula, 4-in. glass plate, shellac and brush, 250 cc. glass graduate, balance sensitive to one-tenth of a gram with metric weights, briquette spacer, screw driver.

Operations. Remove upper segment of the ball mill and thoroughly clean the interior of both parts. Thoroughly clean the rock sample; if necessary, wash it on a screen. Put 500 gm. of the sample and about 90 cc. of water into the mill and bolt the top segment tightly in place. Start the mill and grind for $2\frac{1}{2}$ hours; the speed of rotation should be about 2000 revolutions per hour; note the speed. Remove the paste from the mill with the spatula. The paste should be stiff.

Mould this paste into cylinders, usually called briquettes, in the briquette forming machine. These briquettes are 25 mm. in diameter; determine by trial the amount of paste required to make a briquette 25 mm. high after the pressure has been applied. After sufficient paste for one briquette has been put into the compression chamber and the cap has been screwed tightly into place, balance the poise arm for zero load. Then gradually apply loading up to a total of 1429 lb. (132 kg. per sq. cm. of paste). Make the total period during which the paste is in compression from zero to 1429 lb. equal to 30 seconds. The maximum load should be applied only for an instant. Remove the briquette and place it on the 4-in. square of glass. Be careful not to injure it. Mould seven briquettes.

Allow the briquettes to dry on the glass plate for 20 hours in air at room temperature. Then in the hot-air bath at 200° fahr. for 4 hours, then cool for 20 minutes in the desiccator.

Test the briquettes in the Page impact machine. Place with two pasters a sheet of metallic paper around the recording drum. Measure to one-tenth of a millimeter the height of the briquette to be tested. Set the spacer at this height and insert it between the table of the machine and the flat surface of the spherical-seated bearing in the crosshead. With the spacer in this position, which the briquette will occupy, adjust by trial the automatic release for zero drop of hammer.

Note the scale reading; then advance the release 1 cm., which will give the hammer a drop of this amount. Place the specimen symmetrically under the spherical-seated bearing; to prevent shifting under impact fasten it to the table of the machine with some shellac. Clamp the spring of the recording lever so that the pointer presses firmly against the drum. Start the machine and test the briquette to destruction. Test the best five briquettes.

The number of blows up to the one when the resilience of the briquette is destroyed indicates the binding power of the dust. Tabulate the results and compute the mean number of blows for the briquettes tested. So far as indicated by the binding power of its dust what is the value of this rock for macadam roads?

References.

1. Bulletin 44, Office of Public Roads, U. S. Department of Agriculture.
2. Columbia School of Mines Quarterly, Vol. 26, No. 2, pp. 83-110.
3. Roads and Pavements, Baker, 1905 edition, pp. 177-195.

HARDNESS TEST OF MACADAM ROCK

Purpose. To determine the hardness of macadam rock.

Material. Two samples of different kinds of stone, each consisting of a cylindrical rock core, 25 mm. in diameter, squared at both ends and about $1\frac{1}{2}$ in. long.

Apparatus. Dorry hardness machine, abrasive agent consisting of standard quartz sand, size between 30 and 40 mesh, balances sensitive to one centigram with metric weights.

Operations. Weigh each rock core to the nearest centigram. Insert the rock cores into the holders and clamp. Put the holders in position so that the cores bear on the revolving table. Each holder weighs 1250 gm. Between the bottom of each core and the grinding surface of the revolving cast iron table spread a layer of quartz sand about one grain deep and extend this layer slightly beyond the adjacent sand feed. Start the machine and rotate the table for 1000 revolutions. Feed the sand so as to give always a continuous grinding layer between specimens and table as the latter revolves. Then weigh the specimens and, reversing them end for end in the holders, repeat the grinding for another 1000 revolutions. Weigh both specimens again.

The hardness of a specimen is given by the expression $H = 20 - \frac{W}{3}$, where H is the coefficient of hardness and W is loss in weight of core in grams per 1000 revolutions.

Tabulate the four results and calculate the mean values. What is the value of this rock for macadam road construction so far as indicated by its hardness?

References.

1. Bulletin 44, Office of Public Roads, U. S. Department of Agriculture.
2. Proceedings, American Society for Testing Materials, Vol. 13, pp. 983-995.

TOUGHNESS TEST OF MACADAM ROCK

Purpose. To determine the toughness of macadam rock.

Material. Two samples of different kinds of stone, each consisting of a cylindrical rock core 25 mm. in diameter and 25 mm. high, squared at both ends.

Apparatus. Page impact machine equipped with 2-kilogram hammer and plunger with hardened steel hemispherical contact of 1 cm. radius.

Operations. Center one of the cylinders under the plunger and by trial adjust the automatic release for zero drop of the hammer. Note the scale reading. Subject the cylinder to drops of the hammer successively increased from zero by one centimeter. Keep the cylinder well centered under the hemispherical portion of the plunger. The number of blows required to destroy the cylinder represents the toughness. Test the other cylinder similarly.

So far as indicated by its toughness what is the value of this rock for macadam road construction? How does the classification of the rock as determined by individual toughness and hardness tests compare with that determined by the abrasion test?

References.

1. Bulletin 44, Office of Public Roads, U. S. Department of Agriculture.
2. Yearbook, 1914, American Society for Testing Materials, p. 340.
3. Proceedings, American Society for Testing Materials, Vol. 13, pp. 983-995.

ASPHALT

TEST No. 32

PENETRATION TEST

Purpose. To measure the consistency of asphaltic cement at various temperatures.

Material. Three sample cans of asphalt.

Apparatus. Penetrometer, metronome, glass cup with sample-can holder, large agate pan, asphalt thermometer, agate pitcher, Bunsen burner, iron ring stand.

Operations. The penetration of bitumen is the distance in hundredths of a centimeter that a No. 2 cambric needle will penetrate vertically at 77° fahr. The weight under which the needle penetrates and the period of time during which this weight is applied should always be reported. These are made to depend upon the consistency of the bitumen and are determined by measuring the penetration first for a weight of 100 grams and a period of 5 seconds. If the penetration is less than 10, it should be determined using a weight of 200 grams applied for 1 minute; but if the first penetration is between 10 and 300, it should be determined using a weight of 100 grams applied for 5 seconds; while if the first penetration is greater than 300, it should be determined using a weight of 50 grams applied for 5 seconds. Whenever possible the penetration should be measured using a 100 gram weight applied for 5 seconds in addition to the penetration measured for any other stated weight and time as above required. When the penetration is greater than 100, the container should not be less than 1½ in. in diameter. The penetration should be determined at temperatures of 32° fahr., 77° fahr., and 114.8° fahr.

To determine the penetration, heat some water in the agate pan up to a temperature of 77° fahr., then remove the pan from the burner and immerse the three sample cans of bitumen in the water for at least 30 minutes. Stir occasionally with the asphalt

thermometer and maintain this temperature by the addition of hot water as required from time to time as long as any samples remain in the pan. Clean the needle. Remove one of the samples to the holder in the glass cup on the penetrometer stand; nearly fill this cup with warm water from the pan and place it under the needle. Lower the frame holding the needle until the needle point almost touches the surface of the bitumen. Clamp the needle in exact contact with the surface of the asphalt by observing through the side of the glass cup its reflection from the surface of the sample. Add to the frame the proper weight so that when released the needle will be under a total load of 100 gm. Bring the rack down gently to the top of the rod of the needle frame and rotate the dial to read zero. Unclamp the needle frame for 5 seconds as determined by the metronome; then reclamp. Again lower the rack as before. The pointer on the dial then indicates the penetration in hundredths of a centimeter. The water in the glass cup should be maintained at a temperature of 77° fahr. while the penetration is being measured. Proceed in testing this sample according to the directions in the first paragraph under the heading, "Operations." Make three determinations of the penetration on the sample. Repeat with the other two samples.

Determine by the above methods the penetration for each of the three samples of bitumen; also at temperatures of 114.9° fahr. and 32° fahr.

Tabulate the results; compute the mean for each temperature.

What factors determine the penetration of bitumen to specify for any given case? Tabulate desirable values under several varying conditions.

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. The Modern Asphalt Pavement, Richardson, pp. 559-567.
3. Yearbook, 1914, American Society for Testing Materials, p. 344.
4. Proceedings, American Society for Civil Engineers, Vol. 40, No. 10, Dec., 1914, pp. 2997-3050.
5. Proceedings, American Society for Testing Materials, 1915. Report of Committee D-4 with appendices.

VOLATILIZATION TEST

Purpose. To determine the losses in weight and penetration after heating asphalt.

Material. One sample can of bitumen containing about 20 gm.

Apparatus. Constant-temperature hot-air oven, two chemical thermometers reading from 0° to 250° C. Analytic balance sensitive to half a milligram with metric weights, tin container, stirring rod, container with fluid bitumen.

Operations. The sample should be free of water. The container should be a cylindrical tin box about 2 cm. deep and 6 cm. in diameter or of such size as to give the same relation between area of exposed surface of asphalt and its volume. The sample is to be heated for five hours in the oven at a constant temperature of 163° C. (325° fahr.). If it foams at this temperature there is water in the bitumen. To remove the water heat the bitumen for five hours at a temperature of 220° fahr.

After removal of the water but before heating the sample determine its penetration at 77° fahr. according to the method outlined in Test No. 32.

Bring the oven to a uniform temperature of 163° C. (325° fahr.) as determined, while the air fans are driven by the clock, by the thermometers inserted through the stoppers in the holes of the cover to the level that the sample will occupy. The bulb of one thermometer should be in air, the bulb of the other in the container of fluid bitumen. Warm some of the sample, just enough to handle conveniently, then put sufficient into the tin container to weigh 20 gm. within 0.2 gm. After cooling weigh container with bitumen to the nearest 0.5 mlgm. Put the container with bitumen to be tested in the oven at 163° C. and allow it to remain there for five hours. During this period the thermometers should not show a variation in temperature from 163° C. greater than 2° C. Then remove the container, allow it to cool, then reweigh it. Note any change in its external appearance.

Determine the penetration of the residue at 77° fahr. in the way this was measured before the sample was heated. But before determining the penetration, melt the residue and stir it thoroughly until it cools.

Calculate the losses in weight and penetration in amount and in percentage.

What do large losses in weight on heating signify? What allowable losses should be specified under different conditions?

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Yearbook, 1914, American Society for Testing Materials, p. 345.
3. The Modern Asphalt Pavement, Richardson, pp. 534-538, 554-555.

SOLUBILITY TESTS

Purpose. To determine the percentages of bitumen which are soluble in carbon bisulphide, in naphtha and in carbon tetrachloride.

Material. Sample of about 20 gm. of asphalt; some carbon bisulphide, carbon tetrachloride; also 60° Baumè and 88° Baumè naphtha, all chemically pure.

SOLUBILITY IN CARBON BISULPHIDE

Apparatus. One 200 cc. Erlenmeyer flask with cork, three prepared porcelain Gooch crucibles, hot-air oven, desiccator, analytic balance sensitive to half a milligram with metric weights, one 500 cc. filtering flask, wash bottle with solvent, thermometer reading from -10° to 110° C., Bunsen burner, iron tripod, platinum crucible, porcelain triangle.

Operations. Dry the Gooch crucible for ten minutes in the oven at 100° C., then ignite it at a low red heat over the Bunsen burner; cool in the desiccator and weigh to 0.5 mlgm. Clean and dry, then weigh the flask, then introduce about 2 gm. of bitumen; obtain exact weight of bitumen by weighing flask plus bitumen. Pour in small portions into the flask about 100 cc. of CS_2 and agitate continually until all lumps disappear. Loosely cork the flask and set it aside for about fifteen to thirty minutes to allow subsidence of the residue.

Place the Gooch crucible in position for filtering. Decant the solution from the flask through the filter without suction, but be careful not to disturb any of the settled residue. Stop decantation as soon as sediment begins to come and let the filter drain. Add more solvent to the flask. Agitate, then allow to settle and decant as before. After the filter is drained, pour on the residue. With solvent remove to the filter any residue which adheres to the flask and wash the residue on the filter until the filtrate is colorless. Apply suction until the odor of solvent dis-

appears from the crucible; then wash the outside of the crucible with some CS_2 . CAUTION: Be careful in using CS_2 ; its vapor is inflammable. Dry the crucible with residue in the oven at 100°C . for about twenty minutes, then cool in the desiccator and weigh.

The insoluble residue may contain both organic and mineral matter. Burn off the former by ignition in the crucible at a red heat until no incandescent particles remain. After cooling in a desiccator reweigh the crucible and determine the percentage of mineral matter. If the mineral matter is finely divided it will pass through the felt of the Gooch crucible.

Check this determination of the mineral matter by making to 0.5 mlgm. the necessary weighings and igniting in the platinum crucible a 1 gram sample of bitumen. When the mineral matter is finely divided it may be determined more accurately by ignition of an original sample than by ignition of the residue on the Gooch crucible.

Report the percentage of bitumen soluble; also the percentages of organic and mineral matter insoluble on the basis of the weight of material taken for analysis. Of what value is the test for solubility in CS_2 ?

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Yearbook, 1914, American Society for Testing Materials, pp. 342-343.
3. The Modern Asphalt Pavement, Richardson, pp. 540-542, 589-594.

SOLUBILITY IN NAPHTHA

Apparatus. Same as for determining the solubility of bitumen in carbon bisulphide, hydrometer.

Operations. With the hydrometer check the specific gravity of each kind of naphtha used as solvent. If necessary bring each to its proper density by dilution with a heavier or lighter naphtha as required. Follow the procedure outlined for measuring solubility in CS_2 . Consult the references before coming to

the laboratory. Consult the instructor if the bitumen does not dissolve readily. In filtering use suction only when filtration by gravity ceases, and then use it sparingly, since it tends to clog the filter. If much insoluble matter adheres to the flask do not attempt to remove it completely but wash it thoroughly with solvent, then dry both flask and crucible for about one hour at 100° C., then cool and weigh.

The percentage of material insoluble in naphtha minus the percentage of material insoluble in carbon bisulphide equals the percentage of bitumen which is insoluble in the former on the basis of total material taken for analysis. In reporting results this percentage should be given on the basis of total bitumen soluble in carbon bisulphide. If x equals the percentage of material insoluble in naphtha and y that insoluble in CS_2 , then the percentage of bitumen insoluble in naphtha equals $\frac{x - y}{100 - y} \times 100$ on the required basis.

Of what significance is this test of bitumen?

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. The Modern Asphalt Pavement, Richardson, pp. 542-544, 592.

SOLUBILITY IN CARBON TETRACHLORIDE

Apparatus. Same as for determining solubility of bitumen in carbon bisulphide.

Operations. Follow the directions for determining solubility in CS_2 except the CCl_4 is to be the solvent.

Report the percentage of bitumen insoluble on the basis of total bitumen soluble in CS_2 as 100 per cent.

For what purpose is solubility of bitumen in carbon tetrachloride determined?

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. The Modern Asphalt Pavement, Richardson, pp. 124, 546, 590.

EXTRACTION OF BITUMEN FROM MINERAL AGGREGATE

Purpose. To determine the percentage of bitumen in a sample of wearing surface.

Material. About 150 gm. of wearing surface.

Apparatus. Dulin Rotarex, 500 cc. carbon bisulphide, balance sensitive to 1 centigram, hammer, small chisel, $1\frac{1}{2}$ in. stiff brush, 600 cc. beaker, sheet of manila paper.

Operations. Chisel the sample into particles about $\frac{1}{4}$ in. in size, weigh out accurately 50 gm. and place in the bowl of the extractor. Put the paper filter hinge in place, then the cover of the bowl. Fasten the cover by screwing down tightly by hand the inlet nozzle for solvent. Introduce sufficient solvent to cover the sample and allow a few minutes for digestion. Place the beaker under the outlet spout, start the motor and add solvent from time to time as required until the effluent is clear. After all the solvent has passed off, stop the motor and brush the aggregate out of the bowl on to the paper to dry; then weigh the dried aggregate. Repeat with another 50 gm. sample. Calculate to the nearest tenth of a per cent the amount of bitumen extracted in each case on the basis of original weight of sample.

Between what limits does the percentage of bitumen in the wearing surface of a sheet asphalt pavement usually lie?

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.

MELTING POINT OF BITUMEN

Purpose. To determine the melting point of bitumen.

Material. About 50 gms. of bitumen.

Apparatus. Iron tripod, Bunsen burner, wire gauze, one 800 cc. Jena glass beaker, one 400 cc. Jena glass beaker, iron ring support, burette clamp, object glass, metal cover, piece No. 12 wire 10 in. long, thermometer reading from 0° to 250° C., $\frac{1}{2}$ in. brass cube moulds amalgamated, amalgamated brass plate, large kitchen spoon, spatula.

Operations. Bitumens have no true melting point, but to determine a so-called melting point the following arbitrary method is of value for purposes of identification, control, and comparison.

By gentle application of heat melt some of the sample in the spoon until it just begins to flow, then pour it into the cube moulds until these are slightly more than filled. When cool, cut off the excess with a hot spatula and remove the cubes from the mould. Bend the end of the wire at right angles and fasten on to it one of the cubes by piercing the center of opposite sides of the cube. Fill the large beaker about half full with water at about 25° C. and mount it over the gauze on the tripod ring so that heat may be applied from below. With the iron ring support suspend the smaller beaker as far down as possible in the water-bath. Through a cork in the metal cover suspend the wire which holds the cube so that the base of the latter is one inch above the bottom of the smaller beaker. Place a piece of paper flat on the bottom of the beaker under the cube. With the burette clamp suspend the thermometer through the circular portion of the triangular hole in the metal cover so that the bulb is on a level with the cube and at an equal distance from the side of the beaker.

With the Bunsen burner heat the water in the larger beaker from below at such a rate that the thermometer indicates an

increase of 5° C. per minute. The temperature at which the bitumen touches the paper at the bottom of the beaker is taken as the melting point. If necessary read the thermometer through the object glass, which is to be placed over the triangular hole in the metal cover and make proper allowance for inclination of sight. Determine similarly the melting point of the other cube.

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Proceedings, American Society of Civil Engineers, Vol. 40, No. 10, pp. 3043-3045.
3. Proceedings, American Society for Testing Materials, 1914, pp. 503-507.
4. Proceedings, American Society for Testing Materials, 1915. Report of Committee D-4 with appendices.

FIXED CARBON

Purpose. To determine the percentage of fixed carbon in bitumen.

Material. About 5 grams of bitumen.

Apparatus. Iron ring support, Bunsen burner, porcelain triangle, platinum crucible with tight-fitting cover weighing complete about 25 gm., crucible tongs, desiccator, analytic balance sensitive to one tenth of a milligram.

Operations. Accurately weigh the crucible, introduce 1 gm. of bitumen, then accurately weigh again. Cover the crucible securely and place it on the triangle. Apply heat, first gently, then more intensely until no more smoke or flame comes from between lid and crucible. Then heat for seven minutes more, holding down the cover with the tongs. The bottom of the crucible should be about 7 cm. above the top of the burner; the flame should be about 20 cm. high when burning free. The outer surface of the cover should burn clear; the inner surface may or may not be covered with carbon.

Cool the crucible in the desiccator; then weigh. Then open the crucible and, holding it in an inclined position over the burner, ignite the contents until nothing but ash remains. Burn off similarly any carbon deposit on the cover. Again cool and weigh crucible and cover with residual ash. Deduct the weight of ash from the weight of residue after first ignition of sample. The difference equals the weight of fixed carbon which is to be calculated in percentage on the basis of total weight of sample exclusive of mineral matter.

Repeat with another 1 gm. sample.

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Proceedings, American Society of Civil Engineers, Vol. 40, No. 10, pp. 3048-3049.
3. The Modern Asphalt Pavement, Richardson, p. 549.

TEST No. 38

DUCTILITY

Purpose. To determine the ductility of bitumen.

Material. About 60 grams of bitumen.

Apparatus. Ductility machine, amalgamated briquette mould and brass plate, three thermometers reading from 0° to 100° C., three rubber stoppers for thermometers, agate dipper with spout for melting bitumen, Bunsen burner, iron ring support, spatula, asphalt thermometer, agate pan, agate pot.

Operations. Heat the bitumen gently in the dipper until it just begins to flow. Place the mould flat on the amalgamated brass plate and pour into it the molten bitumen so as to slightly more than fill it. When the bitumen has cooled cut off the excess with a heated spatula. Remove only the sides of the mould and allow the briquette to remain for thirty minutes in water at 25° C. Stir the water from time to time with the asphalt thermometer and note the temperature; maintain this temperature by adding hot water as required.

Carefully lift the glass cylinder of the ductility machine up from the rubber stopper, and by means of the ends of the briquette mould still attached to the briquette fasten it between the grips of the machine and carefully lower the glass cylinder tightly into place. Fill the glass cylinder with water at 77° fahr. to a point at least 6 in. above the top of the briquette. Take up the slack between the grips and set the pointer to indicate 0 on the scale. Pull the briquette apart at a uniform rate of 5 cm. per minute. The distance the pointer moves up to the time of rupture of the briquette indicates the ductility of the bitumen. If required as the test proceeds add more water to the glass cylinder so that up to the time of rupture the whole briquette is immersed in water at 77° fahr. as indicated by the thermometers

introduced through the rubber stoppers at the three side inlets to the glass cylinder.

Repeat with a second briquette.

References.

1. Proceedings, The American Society of Civil Engineers, Vol. 40, No. 10, p. 3047.
2. Proceedings, American Society for Testing Materials, 1915. Report of Committee D-4 with appendices.

OIL

TEST No. 39

FLASH POINT

Purpose. To determine the flash point of a bituminous oil.

Material. About 800 cc. of oil.

Apparatus. New York State Board of Health oil tester with Bunsen burner, chemical thermometer reading from 0° to 400° C., 6-millimeter glass tubing about 6 centimeters long drawn at one end to a 1-millimeter opening, rubber tubing for gas connection for glass jet.

Operations. Remove inner oil cup and pour water into the bath so that it is full when the oil cup is replaced. For oils which flash above 100° C. cottonseed oil must be used in the bath instead of water. Fill the oil cup with the sample to be tested up to a point about 3 mm. below the flange. Place the glass cover on the oil cup and adjust the thermometer so that its bulb is just covered by the bituminous material. Apply heat so that the temperature of the test sample rises at the rate of 5° C. per minute. The test flame should be about 5 mm. long. When near the flash point insert at intervals of 5° C. the test flame through the opening in the cover half way down to the surface of the sample. Take the temperature at that insertion of the test flame which causes a faint bluish flame to appear over the surface of the sample. This temperature is the flash point.

Repeat the determination.

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Proceedings, American Society of Civil Engineers, Vol. 40, No. 10, p. 3037.
3. The Modern Asphalt Pavement, Richardson, p. 554.

VISCOSITY

Purpose. To determine the relative viscosity of a bituminous oil and water.

Material. About 160 cc. of bituminous oil.

Apparatus. Engler viscosimeter with thermometer, 100 cc. glass graduate, stop watch, thermometer reading from 0° C. to 100° C., agate pot, Bunsen burner and iron ring stand.

Operations. Clean very thoroughly the inner cup and outlet tube. Insert the thermometer through the stopper in the cover of the cup so that its bulb is near the bottom of the cup when the latter is covered. Put the wooden stopper in place and the glass graduate directly under the outlet so that as the water flows out it will not first touch the sides of the graduate. Fill the bath with water and apply heat gently until the temperature of the bath is 77° fahr. Agitate the bath occasionally with the stirrer while this temperature is being maintained. Fill the inner cup with water at 77° fahr. up to the top of the projections. By means of the flame from the ring burner under the bath regulate the temperature of the water in the inner cup to remain constantly at 77° fahr. for at least three minutes, then remove the stopper and with the stop watch determine to the nearest 0.2 second the time required for 50 cc. and 100 cc. to flow out. Repeat the determination with water, then make two similar determinations with the bituminous oil. Take the mean values as the results.

The time in seconds required for a given volume of oil at 77° fahr. to pass through the viscosimeter divided by the similar time for the same volume of water at 77° fahr. equals the specific viscosity of the oil at 77° fahr. for the given volume. Calculate the specific viscosities of the bituminous oil for volumes of 50 cc. and 100 cc. Give the principal dimensions of the Engler viscosimeter.

References.

1. Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.
2. Proceedings, The American Society of Civil Engineers, Vol. 40, No. 10, pp. 3040-3041.
3. Proceedings, American Society for Testing Materials, 1914, pp. 565-616.
4. Proceedings, American Society for Testing Materials, 1915. Report of Committee D-2, Conversion Tables for Saybolt Universal, Engler and Redwood Viscosimeters.

References.

1. Nichols, M., Office of Public Roads, U. S. Department of Interior.
2. Proceedings, The American Society of Civil Engineers, Vol. 2, No. 16, pp. 1919-1921.
3. Proceedings, American Society of Civil Engineers, Vol. 2, No. 16, pp. 1919-1921.
4. Proceedings, American Society of Civil Engineers, Vol. 2, No. 16, pp. 1919-1921.

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